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Assessment of the Impact of Sodium, Potassium, and Calcium Levels on Soil Electrical Conductivity

A Case Study in Eastern Libya.

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Abstract

This paper presents the influences of soil chemical composition on electrical conductivity. Electrical conductivity of 17 samples from various locations which covered about 750 km east of Libya, Chemical compositions such as organic carbon, sodium, potassium and calcium, were measured. The study investigated the efficiency of the extraction method used on sodium, potassium, and calcium from the soil. It was clear that the extraction of sodium could be effective in both extraction methods used with distilled water as well as with an acidic solution, but the effectiveness of the extraction of potassium and calcium was affected whenever the extraction was performed with distilled water by half with potassium, and to less than 1% in case of calcium. Pearson's correlation coefficients studies were employed to highlight the influence of the chemical composition on the electrical conductivity. It had been observed that positive correlation (Pearson correlation, r = 0.329 - 0.958) with all elements used in this study, The Pearson correlation for Na found to bemore than 0.95, which indicates that there is strong positive correlation, moderate positive correlation (r = 0.656 – 0.811) for Ca, and low positive correlation between EC and K(r = 0.329 – 0.362).

Keywords: Electrical conductivity, Soil content, Sodium, Potassium, Calcium, Pearson's correlation coefficient.

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تقييم تأثير تركيز الصوديوم والبوتاسيوم والكالسيوم في التربة على الموصلية الكهربائية:

ساحل شرق ليبيا كدراسة حالة

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الملخص

تتناول هذه الدراسة تأثير التركيب الكيميائي للتربة على الموصلية الكهربائية (EC). تم جمع عدد 17 عينة تربة من مواقع مختلفة تغطي حوالي 750 كيلومترًا من مدينة امساعد حتى مدينة اجدابيا شرق ليبيا. تم تحليل الكربون العضوي (O.M.) والصوديوم (Na) والبوتاسيوم (K) والكالسيوم (Ca). تم استخدام طريقتين لاستخلاص هذه العناصر، الأولى بإستخدام الماء المقطر و الثانية بإستخدام محلول حمضي. تم تقييم كفاءة الطريقتين للاستخلاص و أظهرت النتائج أن استخلاص الصوديوم كان فعالاً باستخدام الطريقتين، بينما انخفضت كفاءة استخلاص البوتاسيوم والكالسيوم بشكل كبير عند استخدام الماء المقطر، حيث انخفضت بنسبة حوالي 50% للبوتاسيوم وأقل من 1% للكالسيوم. تم دراسة تحليل الارتباط لبيرسون لتحديد العلاقة بين التركيب الكيميائي والموصلية الكهربائية. فلوحظ ان هناك ارتباط إيجابي لجميع العناصر التي تمت دراستها ($r = 0.329 – 0.958$). اظهر الصوديوم ارتباطًا إيجابيًا قويًا مع الموصلية الكهربائية($r > 0.95$) ، بينما أظهر الكالسيوم ارتباطًا إيجابيًا متوسطاً($r = 0.656 – 0.811$) ، والبوتاسيوم ارتباطًا إيجابيًا ضعيفًا مع الموصلية الكهربائية.($r = 0.329–0.362$)

الكلمات المفتاحية: الموصلية الكهربائية، محتوى التربة، الصوديوم، البوتاسيوم، الكالسيوم، معامل ارتباط بيرسون

1. Introduction

The relationship between conductivity and the concentration of ions like sodium (Na^+), potassium (K^+), and calcium (Ca^{2+}) in soil can provide insights into soil salinity, nutrient availability, and overall soil health. Electrical conductivity (EC) is a measure of a soil's ability to conduct an electrical current, which is influenced by the

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concentration of ions dissolved in the soil solution (Buelow, Steenwerth, & Parikh, 2015; Disale, Undre, Alameen, & Khirade, 2020). High EC values typically indicate high ion concentrations, which can affect soil fertility and plant growth. Sodium (Na^+), potassium (K^+), and calcium (Ca^{2+}) are essential cations in soil that influence soil structure, nutrient availability, and plant health. Their concentrations can vary depending on factors such as soil type, parent material, land use, and management practices. Elevated levels of sodium ions (Na^+) in soil, often associated with high soil salinity, can disrupt soil structure and reduce water infiltration and plant growth. Monitoring soil conductivity can help assess salinity levels and guide management strategies such as irrigation and soil amendment (Chik & Islam, 2011; Patriquin, Blaikie, Patriquin, & Yang, 1993; Smith & Doran, 1997). Potassium (K^+) is crucial for plant growth and development, playing roles in enzyme activation, osmoregulation, and nutrient uptake. Maintaining optimal K^+ levels in soil is essential for maximizing crop yields and quality. Calcium (Ca^{2+}) is involved in various physiological processes in plants, including cell wall formation, nutrient uptake, and stress tolerance. Adequate Ca^{2+} levels in soil promote good soil structure, root development, and overall plant health. Several studies (Bai, Kong, & Guo, 2013; Carmo et al., 2024; Corwin & Lesch, 2005; Romaneckas et al., 2023; Seo et al., 2022; Valente, Queiroz, Pinto, Santos, & Santos, 2012)have explored for understanding the relationship between soil conductivity and ion concentrations, particularly sodium, potassium, and calcium. This study uniquely contributes to understanding the intricate dynamics of soil ion composition and conductivity by focusing on a geographically significant area about 750 km of eastern Libya. The novelty lies in analyzing the correlations between EC and specific soil cations (Na^+, K^+, Ca^{2+}) across a diverse range of soil samples using Pearson's correlation coefficient. The findings offer a detailed perspective on how these ions interact with soil conductivity under different extraction conditions, providing actionable insights for soil management(El Gendy et al., 2015).Moreover, assessment of extraction of these elements methods were studied and the efficiency of sodium, potassium, and calcium extraction using distilled water and acidic solutions was systematically evaluated, revealing differential extraction efficiencies that significantly impact soil ion analysis.

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The aim of this study is to show the observations of chemical influences (mineral elements and salts) on soil electrical conductivity. Sodium (Na), potassium (K), and calcium (Ca) have been measured for 17 samples from various locations, which cover about 750 km east of Libya, with soil electrical conductivity. The correlations between electrical conductivity and soil parameters were determined using Pearson's correlation coefficient to evaluate the depending of EC values on presents of these mineral elements. By bridging the gap between soil chemical composition and electrical conductivity, this research provides a comprehensive framework for managing soil salinity, optimizing nutrient availability, and improving soil health for sustainable agricultural practices.

2. Experimental

2.1. Study area

Soil samples in this research were taken from 17 locations in eastern Libya over an area of approximately 750 km, so that a sample was taken from every 50 km throughout the area under this study. Figure 1 shows locations on the map of Libya and Table 1 Shows sample Locations.

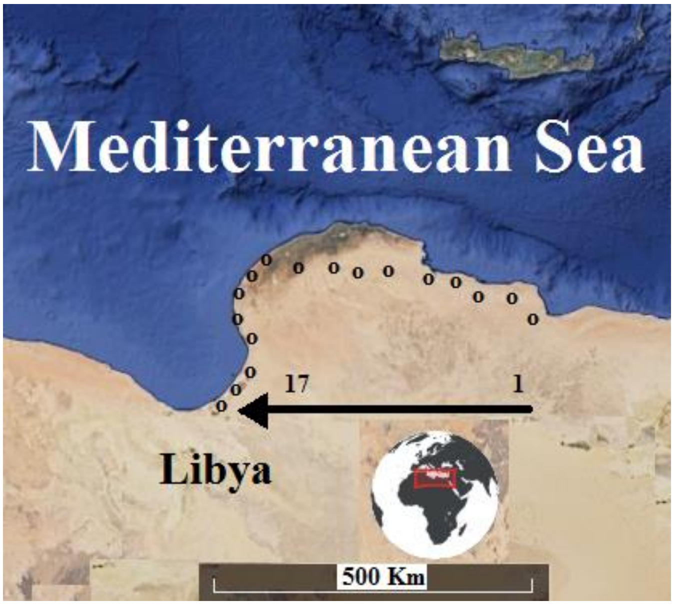

Figure 1. Soil Sample locations on the map of Libya.

Table1. The geographical coordinate numbers on the map for samples location.

Samples No.	Sample Location	
	East	North
1	25.051143	31.640030
2	24.692987	31.882006
3	24.191412	31.953098
4	23.841755	32.080520
5	23.352253	32.140502
6	22.953801	32.277629
7	22.455706	32.170478
8	21.939819	32.196848
9	21.425346	32.193277
10	21.167437	32.426902
11	20.725006	32.500760
12	20.359396	32.374456
13	20.240416	32.103263
14	20.034794	31.982716
15	20.036962	31.614000
16	20.215522	31.260707
17	20.235674	30.837864

2.2. Soil samples collection

Soil samples were collected following the methodology outlined in reference(Hasan, 2015). Specifically, five soil cores were randomly taken from each quadrate plot at a depth of 0-15 cm using an auger. A total of 20 soil cores were obtained from four replicated plots for each stand. The cores from each plot were thoroughly mixed to create a composite sample. Each composite sample was placed in a sterile plastic bag, sealed, and transported to the laboratory. The soil samples were then air-dried, ground, and sieved through a 2.0 mm mesh before being stored at 4°C until chemical analysis was performed.

2.3. Soil chemical analysis

Electrical Conductivity (EC): The specific conductance was determined in the supernatant of a soil-water suspension prepared by mixing 20 g of soil with 50 mL of distilled water. Measurements were performed using a conductivity meter (AD32, ADWA KFT, Romania). The pH of the suspension was concurrently measured

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using an Inolab pH meter 720.Organic Carbon (OC): Soil organic carbon was quantified using the titrimetric Walkley-Black chromic acid wet oxidation method(Walkley-Black, 2017). This method provides an accurate estimation of organic carbon content in soil samples. Calcium (Ca), Sodium (Na), and Potassium (K): The concentrations of calcium, sodium, and potassium were analyzed using a flame photometer (AE-FP8302, AELAB Flame Photometer). Two distinct extraction methods were employed to isolate these elements:

1. Water Extraction: Air-dried soil samples (20 g) were mixed with 100 mL of distilled water and left to extract for 6 hours.
2. Acidic Extraction: Air-dried soil samples (20 g) were mixed with 100 mL of 0.1 M HCl solution and extracted for 6 hours.

Both extraction techniques were designed to effectively displace Na^+, K^+, and Ca^{2+} ions from the soil matrix. The concentrations of these ions in the resulting solutions were subsequently quantified using the AE-FP8302 AELAB Flame Photometer.

3. Results and discussion

Two extraction methodologies were employed to examine the impact of extraction type on the relationship between electrical conductivity (EC) and the concentrations of specific elements in the soil. The first method utilized distilled water as the extraction medium, while the second involved an acidic solution (0.1 M HCl). This approach aimed to explore how the choice of extraction medium influences the mobilization of ions and their subsequent effect on soil electrical conductivity. Using of an acid solution in the extraction process increases the ability for these elements to be extracted. Studying the relationship between these soil elements and their electrical conductivity provides insight into how effectively the two extraction methods describe this relationship and whether significant differences emerge in the results obtained.

Measured soil content in the 17 samples is reported in Table 2 and Figure 2. The low conductivity value (Table 2) is within the conductivity range of soil extracts from other studies (Corwin & Lesch, 2005; Corwin, Lesch, Shouse, Soppe, & Ayars, 2003; Disale, et al., 2020). These observed low values may be due to the low cation exchange capacity of the soil, which is related to the amount and type of clay and organic matter content in the soil. Additionally

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low organic matter content, reflecting low cation exchange capacity and, therefore, low electrical conductivity.

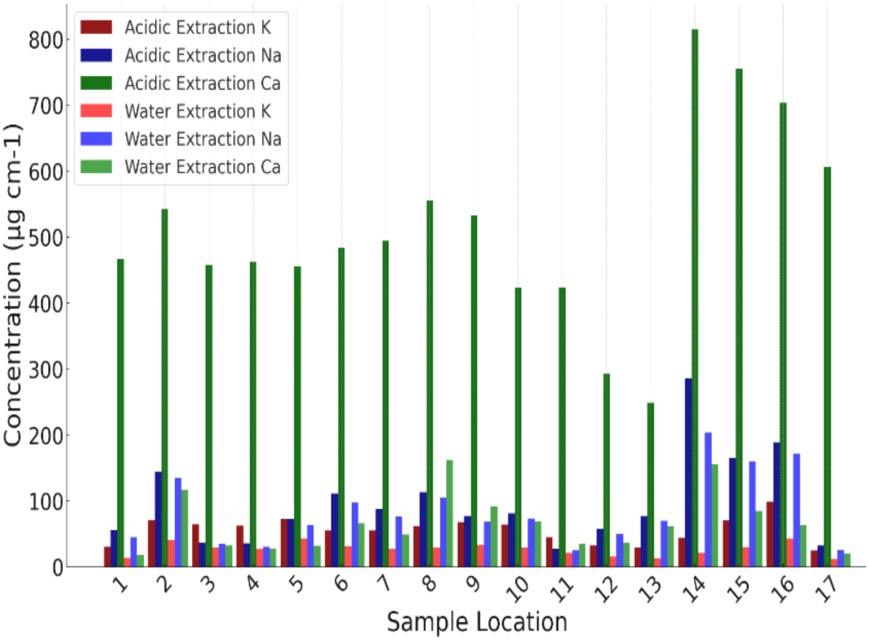

Fig. 2.Comparison of Acidic and Water Extractions for K, Na, and Ca.

The table 2 clearly demonstrates the extraction ratios, (Average of water extraction to Average of acidic extraction) of sodium, potassium, and calcium varies when the extraction method is different. Sodium was extracted using distilled water at a extraction ratio of 87% of comparing with sodium extracted using the acid solution, while potassium was extracted at ratio of 48%, and calcium was extracted at ratio of 0.13%, which is a very weak extraction ratio. The amount of calcium extracted using distilled water from the soil samples may not represent the real amount of calcium in the samples. What is interesting is the results showed that sodium was extracted using the two methods in approximately the same quantities, and this indicates the weak sodium bonded with the soil. In other words, it may have the greatest effect on the electrical conductivity value of the soil.

Table 2.Measured soil contents electrical conductivity (EC), (pH), organic carbon (O.C), potassium (K), sodium (Na) and calcium (Ca).

Samples Location	pH	E.C (µS/cm)	O.C (%)	Acidic Extraction (µg cm^{-1})			Water Extraction (µg cm^{-1})		
				K	Na	Ca	K	Na	Ca
1	8.9	652.0	1.67	30.8	55.9	466.4	13.8	45.1	18.3
2	8.4	1062.3	1.28	70.9	144.6	542.9	40.6	135.0	117.3
3	8.8	284.0	1.64	65.0	37.2	457.7	29.1	35.6	32.6
4	8.8	254.0	1.92	62.7	36.1	462.3	26.9	30.6	28.0
5	8.8	697.0	1.46	72.5	72.5	455.9	43.1	63.1	32.3
6	8.8	990.0	1.42	55.7	111.3	484.0	31.2	98.0	66.3
7	8.9	803.0	0.40	55.8	88.1	494.5	27.8	76.5	49.5
8	8.1	1105.0	0.80	62.3	113.6	555.4	29.1	105.3	161.8
9	8.0	441.7	1.22	68.1	77.2	532.9	33.1	69.0	92.2
10	8.2	315.0	0.88	64.3	81.6	423.3	29.0	73.5	69.4
11	8.3	315.0	1.30	45.2	28.1	423.8	21.2	25.7	35.6
12	8.5	466.0	0.85	32.6	58.4	292.8	15.8	50.1	36.8
13	8.9	322.6	0.77	29.1	77.1	249.1	13.0	69.8	61.9
14	8.2	2293.6	1.35	44.3	285.4	815.0	21.4	204.1	156.0
15	8.7	1655.0	1.29	70.6	165.7	755.0	30.4	160.0	84.8
16	7.7	1715.0	1.70	99.1	189.0	703.7	43.1	172.0	63.5
17	8.5	272.0	0.59	25.3	32.8	606.2	12.1	26.2	20.5
Average	8.5	802.5	1.20	56.1	97.3	513.0	27.1	84.7	66.3

The Pearson correlation coefficients between electrical conductivity (EC) and soil parameters (K, Na, and Ca) under acidic and water extraction methods, as presented in Table 3, provide significant insights into the relationships between soil salinity and nutrient dynamics. Sodium exhibited the strongest positive correlation with EC in both acidic (r = 0.958) and water (r = 0.952) extractions. This indicates that sodium concentrations are closely linked to soil salinity under both extraction conditions. The high correlation underscores sodium’s dominance in contributing to soil EC, reflecting its high mobility and solubility in saline environments. Such behavior is consistent with sodium's role as a major driver of salinity, emphasizing the need for careful management to mitigate its adverse effects on soil structure and fertility, particularly in arid and semi-arid regions. Calcium showed a moderate to strong correlation with EC, with a higher value observed in acidic

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extraction (r = 0.811) compared to water extraction (r = 0.656). The stronger relationship in acidic extraction highlights the enhanced solubility of calcium-containing minerals, such as calcium carbonate, under lower pH conditions. In contrast, water extraction reflects calcium levels predominantly in the soluble phase, which are less directly influenced by salinity. This suggests that calcium availability is governed not only by salinity but also by pH-dependent dissolution processes. Managing soil pH is therefore critical to optimizing calcium accessibility, which is essential for plant growth and maintaining soil structure. Potassium exhibited the weakest correlation with EC under both acidic (r = 0.362) and water (r = 0.329) extractions, indicating that potassium availability is not strongly tied to salinity. Unlike sodium and calcium, potassium is less mobile due to its strong adsorption onto soil particles, particularly clay and organic matter, which reduces its contribution to EC. This limited mobility suggests that potassium dynamics are influenced more by localized soil properties, such as mineral composition and biological activity, rather than broader salinity factors. As a result, enhancing potassium availability may require targeted fertilization strategies and improvements in soil structure rather than relying on salinity management alone. These findings highlight the differential behavior of soil cations under varying salinity conditions and extraction methods. Sodium's strong correlation with EC reinforces its critical role in salinity dynamics, while calcium's moderate correlation demonstrates its dependency on both salinity and pH conditions. Potassium's weak correlation underscores its unique behavior and the need for specialized management practices to ensure its availability. Future studies could further explore the interactions between these parameters by incorporating additional environmental variables, such as soil texture, organic matter content, and mineral composition, to provide a more comprehensive understanding of soil nutrient dynamics and inform sustainable land management practices.

Table 3. Correlation coefficients between EC and soil parameters

Soil Parameters	**Acidic Extraction**			**Water Extraction**		
	K	**Na**	**Ca**	**K**	**Na**	**Ca**
EC Pearson Correlation	0.362	0.958	0.811	0.329	0.952	0.656

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Conclusion

This study investigated the effectiveness of different extraction methods (distilled water and an acidic solution) on extracting sodium, potassium, and calcium from the soil. The results revealed that sodium extraction was effective in both methods, as sodium ions are highly soluble and readily mobilized regardless of the extraction medium. In contrast, the effectiveness of potassium and calcium extraction was significantly reduced when distilled water was used. Specifically, potassium extraction decreased by approximately half, likely due to its lower solubility in neutral pH conditions and its tendency to adsorb onto clay particles and organic matter. Calcium extraction was reduced by a factor of seven, which can be attributed to the low solubility of calcium-containing minerals such as calcium carbonate in water, compared to their enhanced dissolution in acidic conditions. This highlightsthe critical role of extraction medium pH in influencing the availability and mobility of these elements. Additionally, the Pearson correlation coefficient for all elements was analyzed to explore the relationship between electrical conductivity (EC) of the soil and the concentrations of sodium, potassium, and calcium. The study found a strong positive correlation between sodium ion concentration and soil EC, reflecting sodium’s dominant role in influencing salinity. For calcium, the correlation with EC was moderate and dependent on the type of extraction used, suggesting that calcium availability is influenced by both salinity and the pH of the extraction solution. In contrast, potassium exhibited a low positive correlation with EC in both extraction methods, indicating that its mobility and contribution to salinity are relatively limited. Future studies are recommended to investigate additional soil types and alternative extraction solutions to enhance the accuracy of nutrient assessments. Practical recommendations include developing soil management strategies to improve potassium and calcium availability and mitigate salinity issues, alongside exploring advanced analytical techniques to better understand nutrient dynamics in soils.

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